Chapter 2
Design Guidance

2-1. Empirical Performance Data Base

The relationship, shown in Figure 2-1, between severity of seepage and upward gradient through the top stratum at the levee toe was established for 16 sites along the Lower Mississippi River during the 1950 flood (U.S. Army Engineer Waterways Experiment Station 1956). An empirical relationship, shown in Figure 2-2, was developed between the observed field performance indicated in the data base and calculated factors of safety. In developing this relationship, sites were eliminated where the top stratum thickness was less than 5 ft or greater than 15 ft. This relationship is the basis for assigning minimum factors of safety necessary to prevent emergence of an unacceptably large volume of seepage and sand boil initiation at the landside toe of flood control levees.

2-2. Factor of Safety at the Levee Toe, Seepage Berm Toe, and for Relief Wells

a. The factor of safety, FS, used in this guidance is defined as the ratio of the critical gradient $i_{critical}$ divided by the upward gradient i_{upward}. The critical gradient $i_{critical}$ is defined as the numerical difference between the saturated unit weight γ_s of the top stratum and the unit weight of water γ_w divided by the unit weight of water, that is, $i_{critical} = (\gamma_s - \gamma_w)/\gamma_w$. The upward gradient i_{upward} is the excess head of water above the ground level at the landside levee toe divided by the thickness of the top stratum at that location. Figure 2-2 presents the relationship between observed seepage conditions, assumed saturated unit weight of the top stratum, and calculated factors of safety. Assuming the minimum and maximum top stratum saturated unit weight is associated with the lower and upper gradients, respectively, and connecting the points with a straight line, produces the relationship shown. Since the saturated unit weight of the soil was not known accurately at each site, the shape of the curves may be in error. However, the range of the factors of safety is believed to be accurate. Note that sand boils occurred for a computed factor of safety greater than 1 (FS = 1.20 to 1.35 depending on the soil saturated unit weight).

b. Using an average soil saturated unit weight (115 pcf), the factors of safety corresponding to various seepage conditions are:

FS	i_{upward}	Seepage Condition
1.30	0.65	Sand boils
1.53	0.55	Heavy seepage
2.11	0.40	Medium seepage
3.24	0.26	Light/no seepage

c. The minimum value of the factor of safety at the landside toe of the levee should be 2.8. For an average soil saturated unit weight (115 pcf), this is equivalent to an upward gradient through the top stratum at the landside levee toe of 0.30. The gradient of 0.30 corresponded to light to medium seepage (Q_s/H less than 10 gpm/ft net head/100 ft of levee) for the Lower Mississippi River levees during the 1950 flood (Figures 2-1 and 2-2). The factor of safety of 2.8 applies only to new construction, not to existing projects. A factor of safety lower than 2.8 may be used, based on sufficient soil data and past performance in the area.

d. Where no additional seepage control measures are present, relief well systems for agricultural and urban levees should be designed so that i_{max} midway between the wells or landward from the well line should not exceed 0.5 (equivalent to FS = 1.7 for an average soil-saturated unit weight of 115 pcf).

2-3. Computer Program to Use for Seepage Analysis

a. If the soil profile can be idealized with a top blanket of uniform thickness overlying a foundation layer of uniform thickness and seepage flow is assumed to be horizontal in the foundation and vertical in the blanket, then LEVSEEP (Brizendine, Taylor, and Gabr 1995) or LEVEEMSU (Wolff 1989; Gabr, Taylor, Brizendine, and Wolff 1995) could be used. LEVSEEP would be simpler to use.

b. If the soil profile is characterized by a top blanket and two foundation layers of uniform thickness, and seepage flow is assumed to be horizontal in the foundation, horizontal and vertical in the transition layer, and vertical in the blanket, then LEVEEMSU or the finite element method (CSEEP) could be used (Biedenharn and Tracy 1987; Knowles 1992; Tracy 1994; Gabr, Brizendine, and Taylor 1995). LEVEEMSU would be simpler to use.

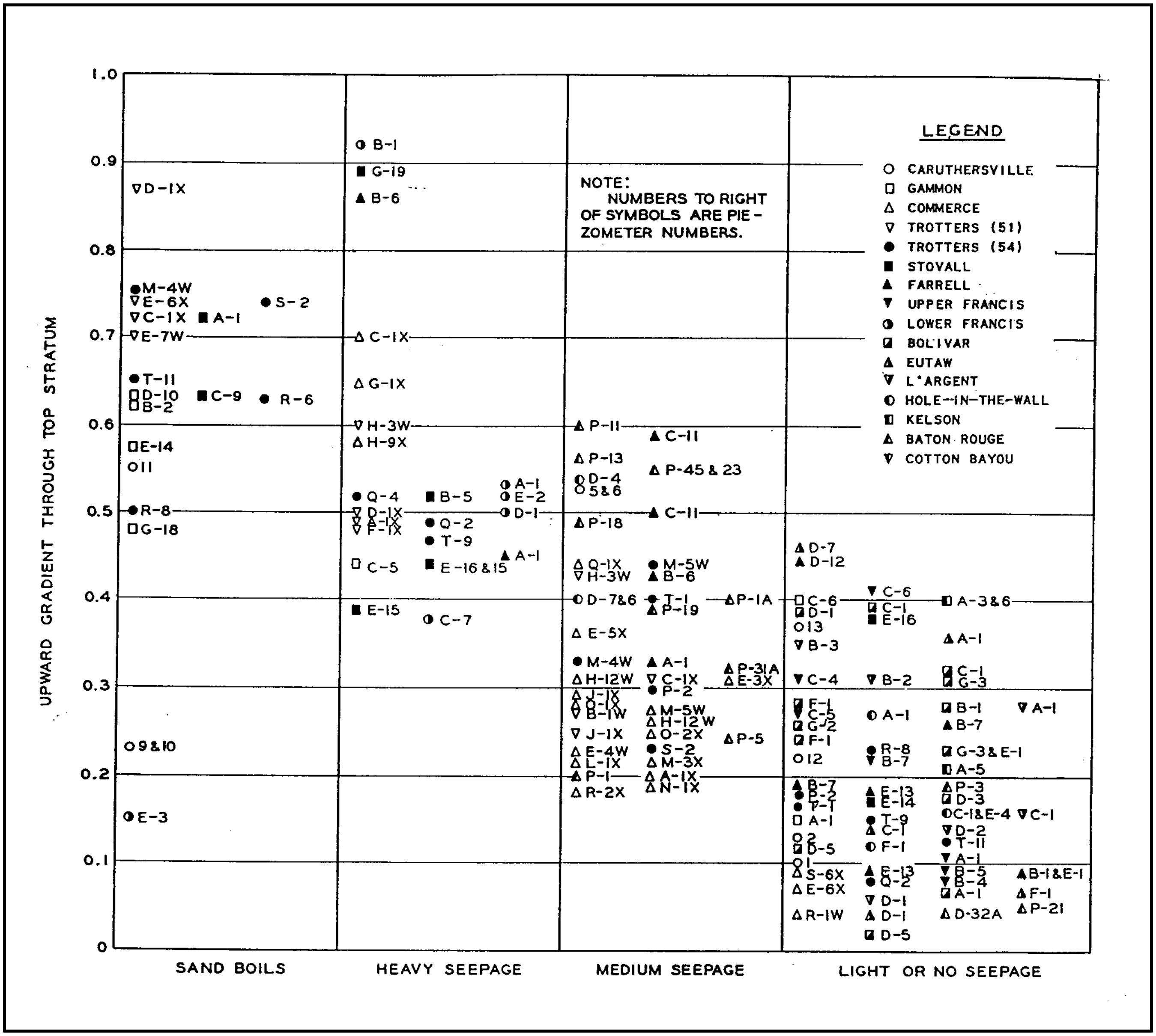

Figure 2-1. Severity of seepage as related to upward gradient through top stratum (from U.S. Army Engineer Waterways Experiment Station 1956, Vol 1, Figure 47, p 272)

c. If the idealized soil profile includes irregular geometry (slopes greater than 1 vertical to 100 horizontal), more than three layers and/or anisotropic permeability ($k_v \neq k_h$), then only the finite element method (CSEEP) is applicable. When using CSEEP it is recommended that FastSEEP, a graphical pre- and post processor, be used for mesh generation, assigning boundary conditions and soil properties, and viewing the results (Engineering Computer Graphics Laboratory 1996).

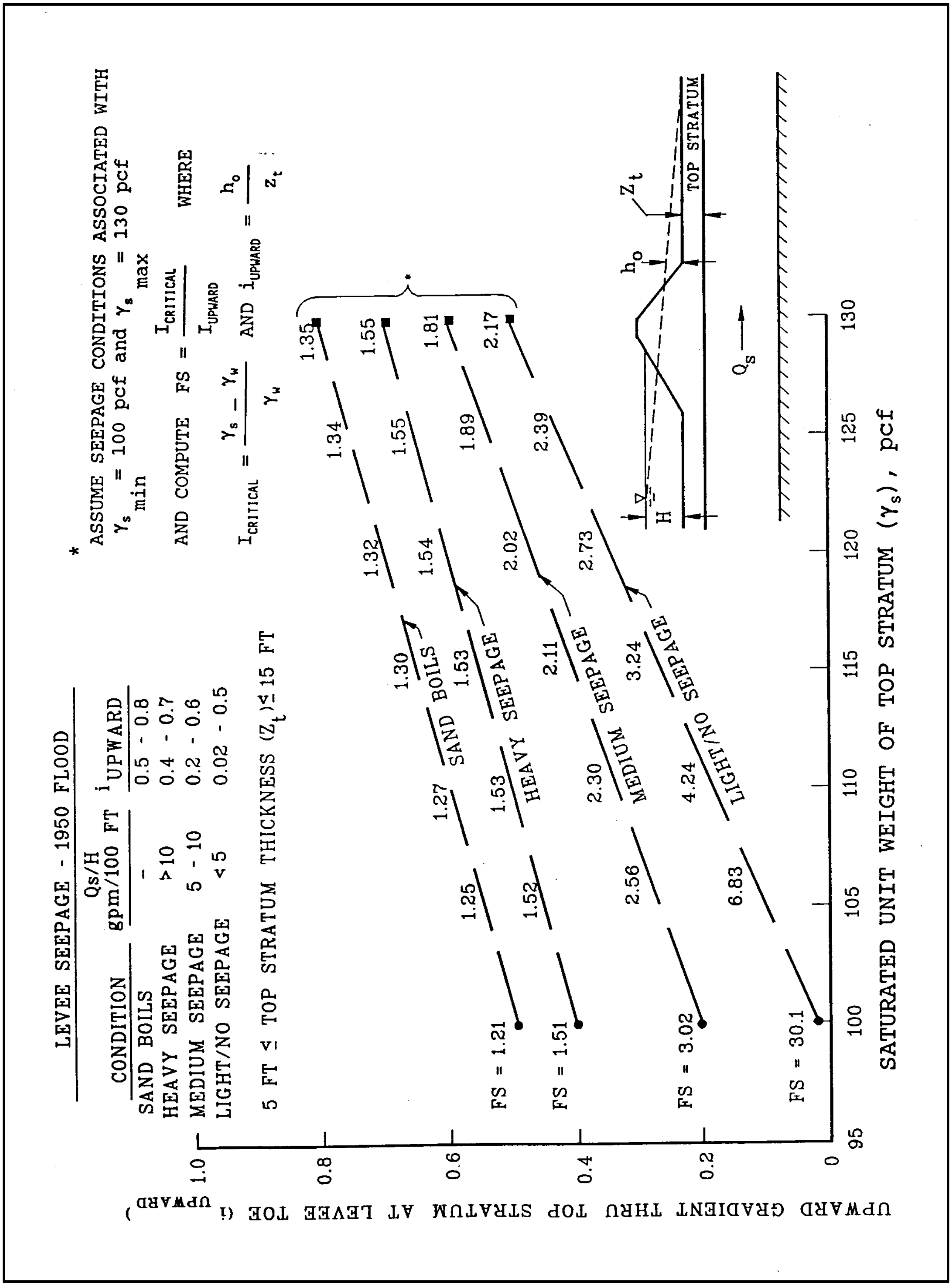

Figure 2-2. Relationship between seepage condition and factor of safety for Mississippi River levees based on 1950 flood (adapted from U.S. Army Engineer Waterways Station 1956, Vol1, Figure 47, p 272)